Multi-Wavelenght Tomography of the Solar Corona: First Steps

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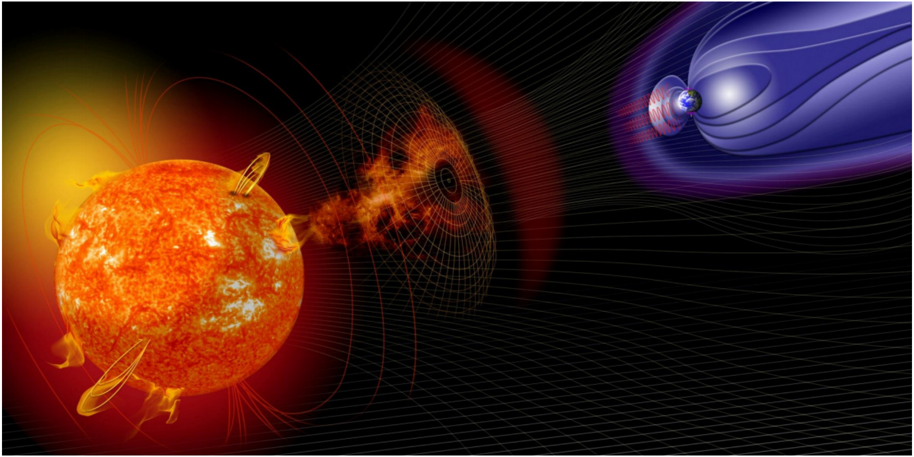
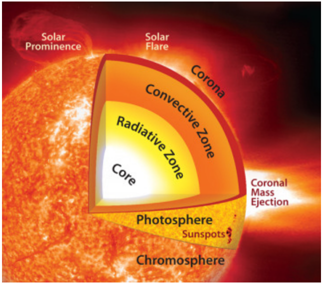
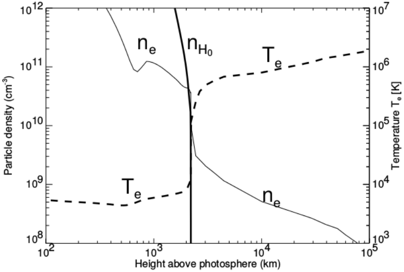
Solar Corona and Sun-Earth relation



Being the place where the solar wind is heated and accelerated, and impulsive events as solar flares and coronal mass ejections are released, observation and modeling of the Solar Corona is of great relevance to advance our understanding of the Sun-Earth environment.

Solar Corona





Corona (T $\approx 1 - 10$ MK, $n \approx 10^{10-7}\ \mathrm{cm}^{-3}$)

- The corona is optically thin in the UV, EUV, X, WL ranges.
- Images are thus 2D projections of the underlying 3D emitting structure.
- Advancement of physical models is in need of 3D information of the coronal fundamental parameters $\mathbf{B}$, N_e, T_e and chemical abundances.

Tomography

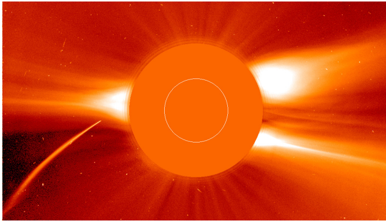
By inverting for the 3D EUV emissivity from time series of images it allows inferring the 3D N_e and T_e of the global corona.

Solar Rotational Tomography (SRT)

The object of study is the solar corona.
The solar rotation provides the necessary 360°view angles.

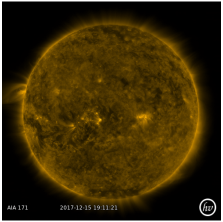
- Corona-K: Thomson scattering of photospheric white light (WL). Data gathered with WL coronagraphs.
- SRT-WL → 3D N_e.
- 1st SRT-WL: Altschuler & Perry (1972)

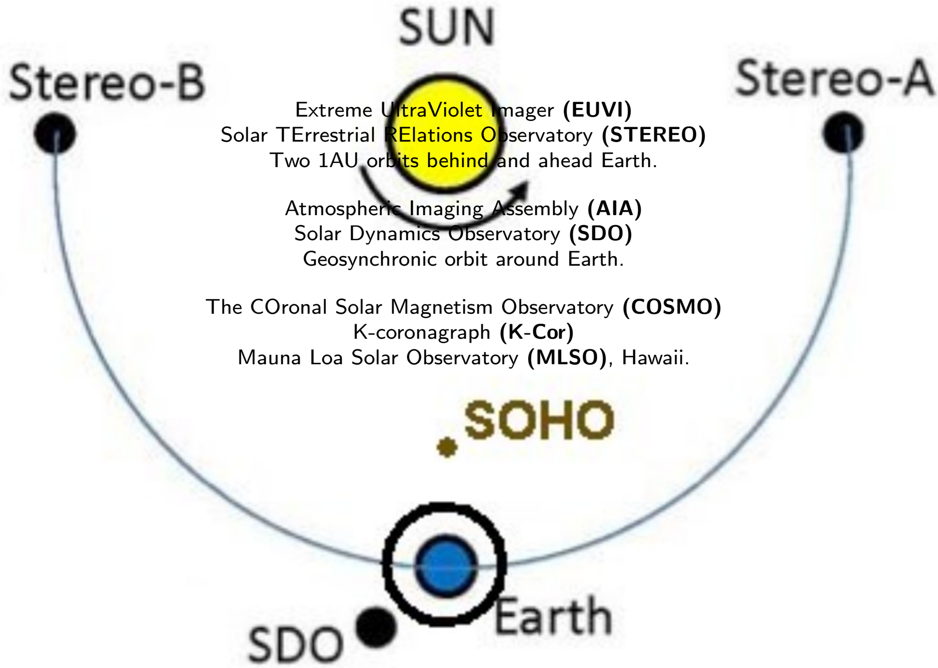
White Light



- Corona-E: True coronal emission by ions UV, EUV y X.
- SRT-EUV → 3D EUV emissivity → 3D N_e y T_e
- 1st SRT-EUV: Frazin et al. (2009)

EUV





Extreme UltraViolet Imager **(EUVI)**
Solar TErrestrial RElations Observatory **(STEREO)**
Two 1AU orbits behind and ahead Earth.

Atmospheric Imaging Assembly **(AIA)**
Solar Dynamics Observatory **(SDO)**
Geosynchronic orbit around Earth.

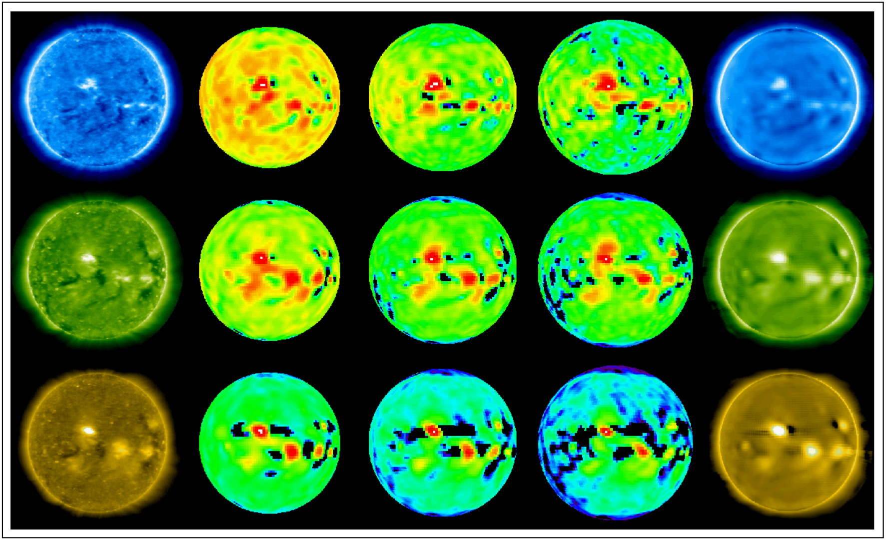
The COronal Solar Magnetism Observatory **(COSMO)**
K-coronagraph **(K-Cor)**
Mauna Loa Solar Observatory **(MLSO)**, Hawaii.

Data Images → 3D Band Emissivity → Synthetic Images

171 Å

195 Å

284 Å

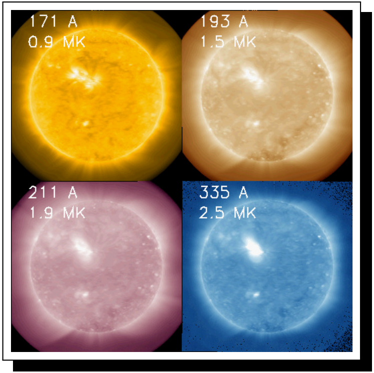


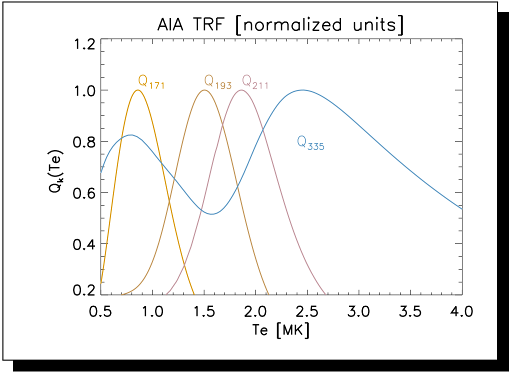
1.035 $R_\odot$ 1.085 $R_\odot$ 1.135 $R_\odot$

Vásquez et al. (2016)

Characteristic Temperatures of the Solar Corona

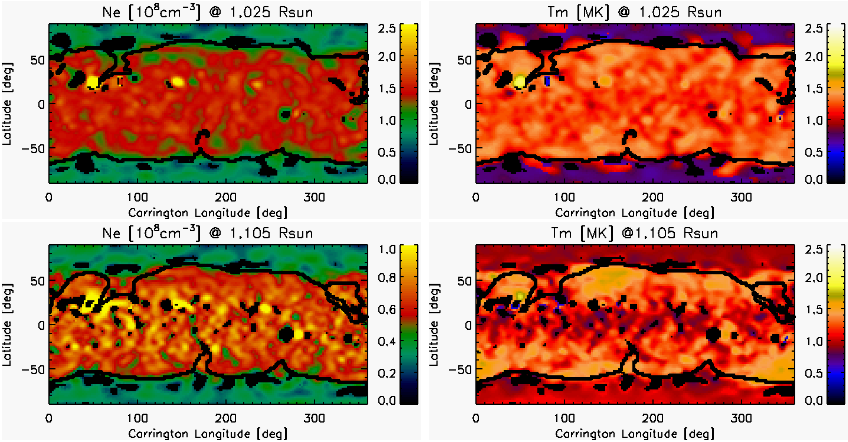
EIT/SOHO and EUVI/STEREO 3 bands: 0.5-2.75 MK
AIA/SDO 4 bands: 0.5-4.0 MK,





Example of EUV Tomography

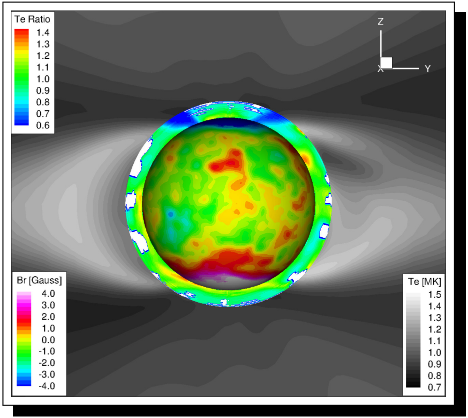
Minimum 2009 Extreme UltraViolet Imager

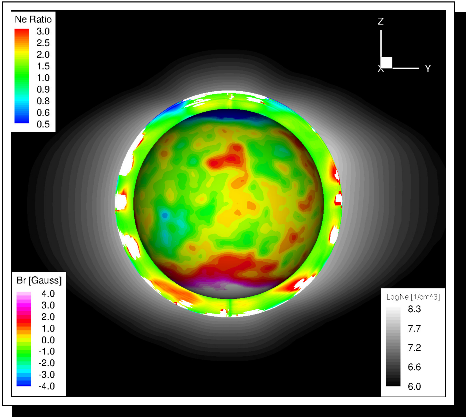


(Lloveras et al. 2017) $\rightarrow$ Systematic incertainties in DEMT results $\sim 10\%$

DEMT as MHD Validation Tool (Jin et al. 2012)

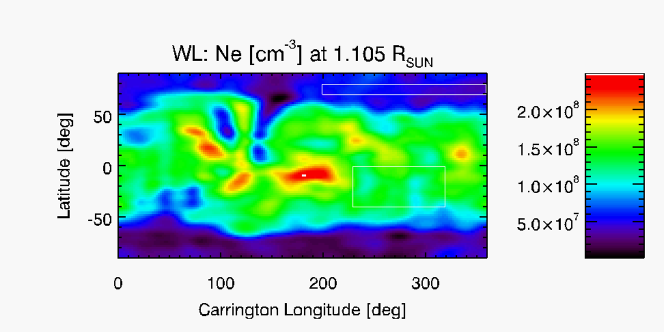
AWSoM / Space Weather Modeling Framework (Univ. of Michigan)

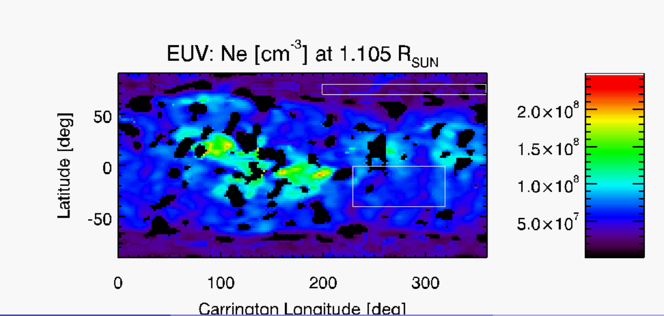




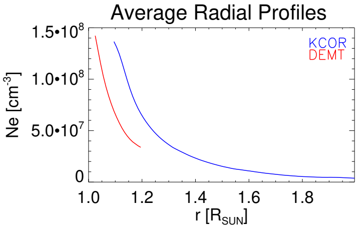
- Inner Ring (1.00 - 1.25 $\mathrm{R_{SUN}}$): Ratio MHD/DEMT.
  - Outter Greyscale map ($> 1.25\ \mathrm{R_{SUN}}$): MHD Model.
  - Color Sphere: $B_r(1\,\mathrm{R_{SUN}})$.

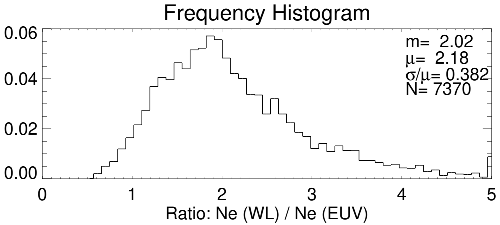
Multi-wavelength Tomography: First Results



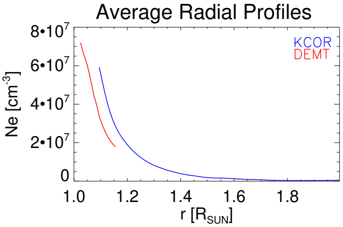


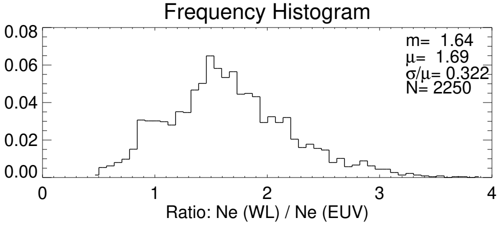
Quiet Sun in Streamer Region





Subpolar Open Region





Discussion

- $E_{\mathrm{EUV}} \propto \left\langle N_e^2 \right\rangle = f \, \left\langle N_e \right\rangle^2$, where filling factor is defined as $f \equiv \left\langle N_e^2 \right\rangle / \left\langle N_e \right\rangle^2$
- $E_{\mathrm{WL}} \propto \left\langle N_e \right\rangle$
- Then: $\left\langle N_e \right\rangle_{\mathrm{WL}} / \left\langle N_e \right\rangle_{\mathrm{EUV}} \propto \sqrt{f}$
- If differences in the results are solely attributed to filling factor: $f \sim 2$ in subpolar open region, and $f \sim 4$ in quiet sun closed region.
- Note that: $\sigma_{Ne}^2 \equiv \mathrm{Var N_e} = \left\langle \mathrm{N_e^2} \right\rangle - \left\langle \mathrm{N_e} \right\rangle^2 = \left\langle \mathrm{N_e} \right\rangle^2 (\mathrm{f} - 1)$
- So that: $\sigma_{Ne} / \left\langle N_e \right\rangle = \sqrt{f - 1}$.
- With this interpretation, where f is larger (quiet sun closed region) the electron density probability distribution has larger variance.

Future Work

- Other factors can partly explain the observed differences, as [Fe].
- To refine discrimination of different structures we will next trace results along field lines from MHD models.
- This work (in progress) is a first step towards future implementation of Multi-Instrument Tomography (MIT).
- Future work: MIT aims at using tomographies in WL, EUV and also visible spectral lines (upcoming UCoMP instrument) to simultaneously derive reconstructions for the different physical parameters $\langle N_e \rangle, \sigma_{Ne}, f, [\mathrm{Fe}]$, as well as $\langle T_e \rangle, \sigma_{Te}$.

Thanks a lot for your attention!